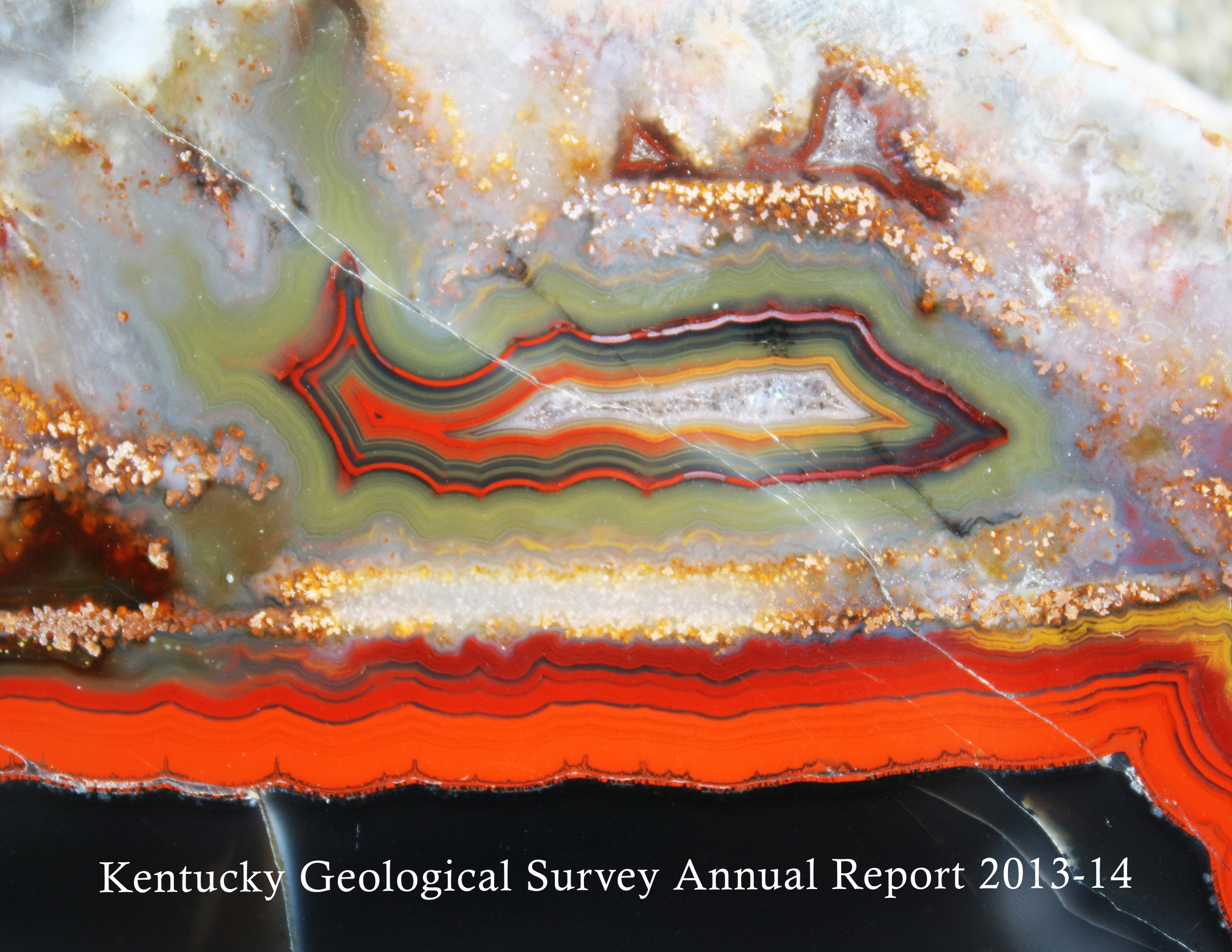
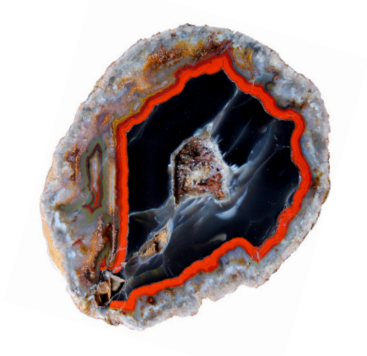


Kentucky Geological Survey Annual Report 2013-14

OUR MISSION
is to increase knowledge
and understanding of the mineral,
energy, water resources, geologic hazards,
and geology of Kentucky for the benefit
of the commonwealth and nation.

COVER PHOTO
by Steve Greb, KGS
from a specimen donated to the Survey by agate
collector Roland McIntosh.
A photo of the full specimen is below.



Agate is a variety of the mineral quartz. The color banding is usually related to chemical impurities. Iron, for example, results in a red or orange color, and manganese or calcium result in black or blue colors. Beautiful specimens of agate have come from the Renfro and Borden Formations of Early Mississippian age in eastern Kentucky.

Many agate pictures can be found in "Kentucky Agate: State Rock and Mineral Treasure of the Commonwealth," by McIntosh and KGS geologist Warren Anderson.

Information on agate is also available under the General Geology link on the KGS home page.

UNIVERSITY OF KENTUCKY®
Kentucky Geological Survey

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Background photo:
Scenic overlook at Natural Bridge State Park in Powell County, Ky.
Photo by Bart Davidson, KGS

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Letter from the Director

The 2013-14 annual report brings to a conclusion the 12th Kentucky Geological Survey. Since David Dale Owen was appointed in 1854, each successive state geologist presided over a numbered series of publications and accomplishments. Jim Cobb's retirement from UK in July 2014 ended his highly productive 15-year tenure as state geologist. When Jim took office in 1999, he set his highest priority at making all the Survey's maps and geoscience data available to the public over the World Wide Web. KGS became a pioneer in developing this technology and has gained a national and international reputation for data dissemination. We now serve geoscience data to hundreds of users every day. More than 1,300 new publications were issued during the 12th Survey, including reports, maps, and electronic data sets. One of the most significant achievements was the digital conversion of Kentucky's 1:24,000-scale geologic maps. This seamless statewide database of geologic maps underpins our online geologic map service and facilitated the publication of new 1:100,000-scale geologic map compilations. Meanwhile, the search for the next state geologist is under way.

Changes in use of fuels within the electric power industry are leading to increased demand for natural gas supplies. Gas production in Kentucky nearly tripled in 2009 and has sustained more than 250 billion cubic feet per year since that time. This increased production has been a result of wider use of horizontal drilling techniques. Oil production, which had been declining for many years, has seen recent increases in production because of the higher oil prices as well as the use of horizontal drilling techniques in conventional reservoirs. KGS has established a new industry-supported research program to study the Berea Sandstone oil play in northeastern Kentucky, which employs horizontal drilling. KGS is also developing an initiative with surrounding states to investigate the potential for unconventional oil development in the New Albany Shale in the Illinois Basin. This year also marked the completion of a 6-year study to evaluate potential

for CO_2 injection and storage in deep geologic formations, funded by the 2007 Kentucky Energy Act.

Eastern Kentucky continues to face serious challenges from declining coal production related to market conditions, electric utility fuel switching, and the high cost of mining in the region. In 2013, eastern Kentucky coal production had decreased 63 percent from the year 2000 and employment dipped to fewer than 12,000 miners. Western Kentucky coal production has been increasing since the early 2000's, and exceeded eastern Kentucky production in 2013 for the first time since 1910. One of the bright spots for eastern Kentucky coal is increased international exports, both in metallurgical and steam power markets. KGS completed a study of metallurgical coal resources to assess the quality of coals for these markets. A new Department of Energy–funded initiative is under way, led by the UK Mining Engineering Department, to characterize the rare-earth element content of Kentucky coal beds and their post-combustion byproducts. KGS is participating in that program.

Kentucky's citizens and industries depend on the availability of more than 5 billion gallons of surface water and groundwater every day. Our distinctive geography and geology, influenced by extensive karst systems and fractured aquifers, make monitoring, characterizing, and protecting this essential resource extremely challenging. KGS has traditionally focused on groundwater hydrogeology, but integrating surface and groundwater systems analysis has become increasingly important. KGS has established a world-class environmental laboratory at the Kentucky Horse Park for just this purpose. We also are developing capabilities to monitor groundwater levels in different parts of the state to better understand the response of these systems to variations in weather patterns and withdrawals.

Geologic hazards were prominent in the news media during 2013-14, with catastrophic sinkhole collapses in Kentucky and Florida, and the devastating landslide in Oso, Wash. Kentucky is generally not known for major hazard events that garner national media attention, but the insidious occurrence of landslides, sinkholes, and rockfalls results in millions of dollars in damage every year. KGS has very active programs to identify and characterize hazard-prone areas of the state.

Geologic maps provide the foundational data that facilitate our research programs and support economic and infrastructure development across the state. The bedrock maps completed under the cooperative KGS-USGS program in 1978 have provided four decades of economic returns to Kentucky. The Geologic Mapping Section of KGS is in the midst of producing a new set of surficial geologic maps that will have similar benefits for land-use, hydrologic, and hazards characterization.

These are just a few of the important issues that relate to the mission and legislative mandates of KGS and highlights of our programs to address them. I invite you to read further details in this report about the achievements and people of KGS.

Interim Director

Energy and Minerals

KGS staff investigate a changing world of energy and mineral needs

The evolving demands for conventional and unconventional energy resources, as well as concerns for the disposal of carbon dioxide produced by energy use, motivate research in the Energy and Minerals Section of KGS. The developing need for domestic minerals and rare earth elements have renewed interest in Kentucky's resources.

Rick Bowersox watches the testing at the Carter County deep stratigraphic research well.

Carbon Storage

Kentucky Energy Independence and Incentives Act Carbon-Storage Demonstrations

Research during the year involved data interpretation and documentation of demonstration projects conducted in 2012-13: the eastern Kentucky deep test well in Carter County and the CO_2 enhanced gas recovery pilot project in Johnson County.

Devonian Shale Enhanced Gas Recovery Demonstration Using CO_2

Brandon Nuttall led a project in Johnson County to test the hypothesis that Devonian black shales beneath about two-thirds of Kentucky may serve for long-term CO_2 storage and play a role in enhanced natural gas recovery. In addition to State funding, support for this project continued from the U.S. Department of Energy through a contract with Advanced Resources International. In September 2012, flow rates and pressures were tested under a variety of conditions. Three monitoring wells and downhole instruments recorded the data. Geophysical logs were acquired before and after the test for comparison. Eighty-seven tons of CO_2 was pumped into the shale of the test interval in three stages. Nuttall completed the data interpretation during the fiscal year and made two presentations on the project. The final report for this project is in progress.

Eastern Kentucky Coal Field Deep Saline Injection Well

Steve Greb, Rick Bowersox, and **Warren Anderson** completed well-site activities and continued to analyze data collected from the 4,835-foot-deep stratigraphic research well drilled in April 2013 in the Eastern Kentucky Coal Field. KGS partnered with Hanson Aggregates (a subsidiary of Lehigh Hanson Inc.) for access to the drill

site in northern Carter County. Well testing was conducted in August 2013, and was preceded by sampling formation brines from the Copper Ridge Dolomite and Rose Run Sandstone. **Marty Parris, Steve Webb,** and **Jerrad Grider** conducted the brine sampling and on-site analysis. Extensive analysis was done on the brines in order to determine their chemical composition and allow modeling of potential reactions with injected CO_2. Several porous zones in the Knox and Mount Simon (basal) Sandstone were evaluated using EPA step-rate test protocols. All tests were conducted using fresh water purchased from the Grayson municipal water system. No CO_2 was injected in this well because of operational and budgetary constraints. The deepest Mount Simon Sandstone interval was found to have low permeability, but intervals in the shallower Copper Ridge Dolomite and Rose Run Sandstone had excellent permeability and would be suitable for carbon storage. Analysis of core from overlying strata shows excellent sealing characteristics in the Upper Ordovician shale interval. After testing at the well site was completed, the well was permanently plugged and the drill site was graded and seeded in accordance with agreements with Hanson Aggregates and the State. A final report on the project will be completed in late 2014.

Marty Parris prepares to take brine samples at the Carter County deep stratigraphic research well.

Regional Carbon Storage Partnerships

Brandon Nuttall, Tom Sparks, and **Steve Greb** continued research in phase III of the Midwest Regional Carbon Sequestration Partnership funded by the U.S. Department of Energy. Managed by the Battelle Memorial Institute, the project covers Indiana, Kentucky, Maryland, Michigan, New Jersey, New York, Ohio, Pennsylvania, and West Virginia. Phase III research continues regional characterization of reservoirs and confining intervals, and injection testing (in other states) to help prepare for future possible commercialization of carbon storage. KGS will continue to work with the partnership's geologic research team to investigate subsurface geology and refine models for estimating geologic carbon storage options in shales across the region, especially those that have the potential to utilize CO_2 for enhanced oil or gas recovery. Information about the regional partnership (fact sheets, reports, presentations, etc.) can be found at www.mrcsp.org.

Evaluating Deep CO_2 Storage in the Illinois and Michigan Basins

This project, funded by the U.S. Department of Energy beginning in 2010, is a collaborative effort of the state surveys of Illinois, Kentucky, and Indiana and geologists at Western Michigan University. The carbon-sequestration potential of the Cambrian-Ordovician Knox Group and Ordovician St. Peter Sandstone of the Midwest is being studied. KGS is characterizing the potentially important Knox Group in western Kentucky.

Dave Harris continued Knox reservoir characterization with analysis of Knox cores from Trigg and Union Counties. Regional correlations were completed to document the distribution of quartz sandstones present in the Knox Group. These sandstones form important reservoir intervals in the KGS No. 1 Blan well, and can be correlated into Indiana and northern Kentucky. A final project report is in progress.

Junfeng Zhu of the KGS Water Resources Section completed geochemical models to predict interactions among supercritical carbon dioxide, brines, and the minerals making up the Knox carbonate reservoir and seal rocks. These new models incorporated sulfur dioxide, a contaminant likely to be present in carbon dioxide separated from flue gas. **Marty Parris** and a consultant continued to revise a paper on reactive transport modeling to predict reactions between CO_2-saturated brines and confining zones (shale or nonporous carbonates).

Oil and Natural Gas Resources

Berea Sandstone Petroleum System Consortium

Shallow horizontal drilling activity targeting oil in the Upper Devonian Berea Sandstone has increased

dramatically in the last 2 years in northeastern Kentucky. To better understand this new Berea oil play, **Marty Parris, Steve Greb,** and **Cortland Eble,** together with the U.S. Geological Survey and the Ohio Geological Survey, have formed an industry-funded consortium to study the Berea and related hydrocarbon source rocks in eastern Kentucky and southeastern Ohio. This project has been conceived to better our understanding of the Berea oil play, but has broader applications in evaluating the oil and gas potential of low-maturity source rocks in other areas. Specific questions to be addressed include:

1. *Why does the Berea produce oil and gas in areas where the prospective source rocks—the over- and underlying Sunbury and Ohio Shales, respectively—are interpreted to be thermally immature with respect to the hydrocarbon phase produced?* KGS and partners will evaluate the thermal maturity, total organic carbon, and hydrocarbon generation potential of the Ohio and Sunbury Shales.

2. *In light of questions about thermal maturity, are oil and gas produced from the Berea in northeastern Kentucky sourced from shales in the immediate area or have they migrated from deeper in the Appalachian Basin?* KGS and partners will sample organic-rich shales and Berea oil and gas to geochemically tie the hydrocarbons to their source. This will also help to define the limits of oil generation for the Berea source rock.

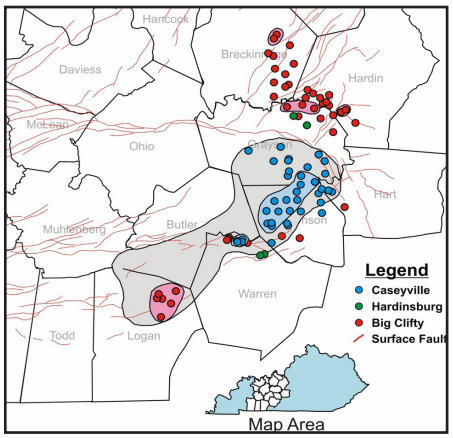
3. *How are pay zones, porosity, and permeability distributed within the Berea?* KGS and partners will interpret the detailed stratigraphy and structure of the Berea in northeastern Kentucky using numerous cores, logs, and outcrops to characterize the Berea lithofacies. This work will provide the stratigraphic and structural framework needed to successfully plan and drill horizontal wells in the Berea interval.

The project proposal to conduct research to answer the above questions was written and submitted to industry early in 2014. In response, eight industry partners have agreed to fund the study. Two other companies are providing in-kind research contributions. Research began August 1, 2014, and will continue for 18 months.

Evaluation of Heavy Oil and Tar Sand Resources, Western Kentucky

Rick Bowersox continued work on his evaluation of the western Kentucky heavy oil and bitumen resources (tar sands) in response to increased industry interest. A zone of heavy oil- and bitumen-saturated zones in the Late Mississippian Big Clifty and Hardinsburg Sandstones and Early Pennsylvanian Caseyville Formation occurs primarily in a belt of eight counties from Logan County on the south, north to Breckinridge County. These surface rock-asphalt deposits were mined for use in road paving from 1889 to about 1955. Shallow oil wells, less than 600 feet deep, yielded only very low, noncommercial production of the tar-like oil from these formations.

Records from 3,930 wells and 164 coreholes were reviewed to construct thickness contour maps and calculate reservoir volumes in the Big Clifty, Hardinsburg, and Caseyville formations. Analysis from more than 3,800 core plugs from 150 cored intervals and 113 surface samples from historic quarries was used to calculate the bulk-volume oil in place in the formations. A report is being prepared that will provide detailed results of this research, including estimated oil in place for each zone.



Tar-sand outcrops in western Kentucky being studied by Rick Bowersox. Shaded areas show developed surface tar-sand deposits in the Big Clifty (red), developed surface deposits in the Caseyville (blue), and subsurface extent of the combined reservoirs (gray).

Utica Shale Appalachian Basin Exploration Consortium

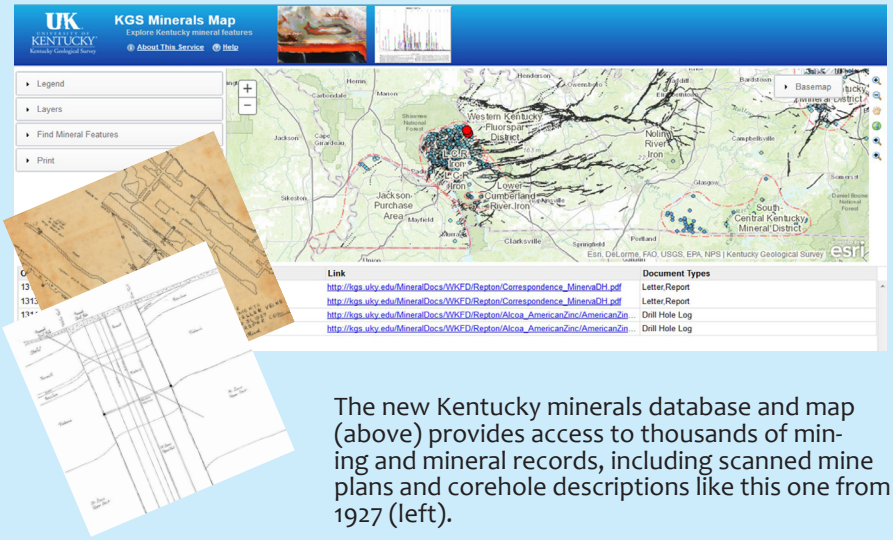
KGS completed a collaborative five-state study of the geology, stratigraphy, and hydrocarbon potential of the Ordovician Utica Shale, an unconventional gas and oil reservoir in the Appalachian Basin. Research was conducted by **John Hickman, Cortland Eble,** and **Jason Backus,** as well as researchers at the Pennsylvania, Ohio, and West Virginia geological surveys, Washington University, Smith Stratigraphic LLC of New York, and the U.S. Department of Energy's National Energy Technology Laboratory.

The research team at KGS analyzed 1,094 sets of rock samples (well cuttings or core) from project wells for total organic carbon content using a carbon/sulfur analyzer in the KGS laboratory. In addition, Eble analyzed 350 samples for organic petrology and measured thermal maturity (percent R_o, vitrinite reflectance) in 90 of those samples from across the five project states. These data were combined with the results from the other four states to produce a cohesive analysis of the potential of the Utica Shale play; the analysis was distributed to the 15 industry sponsors funding this project. Under the terms of the contract, these data will remain confidential for 12 months, after which they will be released to the public.

After the completion of the project, Eble and Hickman hosted an end-of-project core workshop at which about 600 feet of annotated core was on display, including parts of two northern Kentucky cores and one southern Ohio core. The next day, KGS researchers led an all-day field trip to northern Kentucky, along the AA Highway between Maysville and Covington. The 23 participants visited eight outcrops of the Kope and Point Pleasant Formations.

Review of Kentucky Oil and Gas Production, 2010

Brandon Nuttall analyzed the 2010 oil and natural gas production data published by the Kentucky Division of Oil and Gas. These data were examined in response to rules proposed by the U.S. Environmental Protection Agency for limiting volatile emissions from oil and natural gas facilities. Average



The new Kentucky minerals database and map (above) provides access to thousands of mining and mineral records, including scanned mine plans and corehole descriptions like this one from 1927 (left).

KGS Minerals Database

The Kentucky minerals database has been completed and is available online at kgs.uky.edu/kgsmap/KGSMineral. During the past decade, **Warren Anderson** and **Tom Sparks** developed this database, consisting of thousands of mining and mineral records. Scanned documents include core logs, cross sections, mine and property maps, geochemical and geophysical maps, chemical analyses, and unpublished reports. **Doug Curl** was instrumental in building the spatial database and developing the online map service. This database provides access to more than 20,000 files of information about mines and minerals in the state, particularly in the three major districts in central, southern, and western Kentucky. With the opening of a new fluorite mine and additional fluorite exploration drilling in western Kentucky, this information should be very valuable to the mining community. Core data were also included in this database if they contained significant mineral information, particularly in the unmined mineral districts. The database is organized by mine name for western Kentucky, and by county names for central and southern Kentucky. Spatial and tabular information about a mine or mineral site is available, and scanned images can be easily viewed.

An "about this service" file describes the service and gives instructions on how the database was organized. The file has tips on how to use the site and a search function for site-specific names.

This database would not have been possible without the diligent contribution of various geologists, mining and exploration companies who donated records, and researchers, students, and staff who scanned and organized these records. ❖

daily production was determined for 5,044 oil wells and 12,940 natural gas wells. The overwhelming majority of Kentucky's wells are marginal ("stripper") wells that produce at rates of less than 10 barrels of oil (or barrels of oil equivalents) per day or 60 thousand cubic feet of natural gas per day during the months they were operated. These findings were published in Information Circular 30 (series 12).

Coal Resources

Pennsylvanian Geology of the Eastern and Western Kentucky Coal Fields

Cortland Eble and **Steve Greb** continued research on coal-bearing strata in both the Eastern and Western Kentucky Coal Fields. Beds in both coal fields are routinely sampled for inclusion in KGS coal-quality and palynologic databases. New roadcuts on Ky. 15 near Jackson, U.S. 119 between Pikeville and Williamson, and U.S. 460 between Pikeville and Elkhorn City in eastern Kentucky provide exceptional exposures of coal-bearing strata and have attracted both national and international interest. The outcrops are being photographed, measured, and correlated. Finished products will be published in research publications, as cross sections, and as data on the KGS map service. Widely traceable coal beds in the roadcuts provide a high-resolution stratigraphic data set that can be used for better understanding of lateral and temporal variation in coal characteristics, coastal/estuarine depositional facies models, sequence stratigraphy, and subsurface reservoir modelling.

Mineral Resources

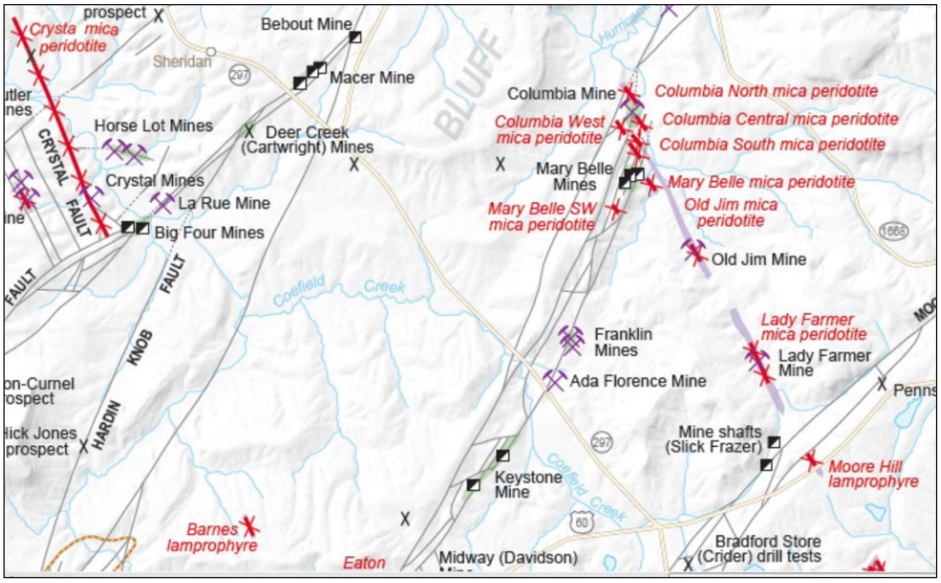
Rare-Earth Element Research

Warren Anderson and **Jason Backus** are concluding their investigation of rare-earth elements in igneous rocks in the Western Kentucky Fluorspar District. More than 60 igneous intrusions have been identified. Both X-ray diffraction mineralogical analysis and induced coupled plasma elemental analysis were performed in the KGS laboratory on samples from selected dikes. These analyses detected enriched rare-earth elements and several minerals.

Because of the enriched rare-earth elements and potential for economic deposits, more research should be conducted in this area.

Fluorite was also examined for potential rare-earth elements, since many fluorites throughout the world contain them. Although rare-earth elements do occur in the ore-stage fluorites in the Western Kentucky Fluorspar District, only slight enrichment was noted and there was no determination of color association or zonation and rare-earth element content. More research using cathodoluminescence petrography and microprobe analysis needs to be conducted to determine timing of mineralization, fluorite coloration, zonation, and rare-earth element content.

Other rock units in the state were also examined for rare-earth elements, including Ordovician phosphates in central Kentucky, Devonian black shale, the Cretaceous McNairy sands, and the Elliott County kimberlite. Although rare-earth elements occur and are enriched in each of these units, mining potential is doubtful, except where recovery might be as a byproduct of other mining operations. If some of these units were mined for phosphates, oil shale, or sands, rare-earth elements might be recovered in tailings. Mining depends on many factors, such as mining costs, economics, and environmental factors.



Detail from the 2013 KGS publication, "Mines and Minerals Map of the Western Kentucky Fluorspar District." The Energy and Minerals Section has been investigating rare-earth elements in igneous rocks in the district.

All analytical work, interpretations, and a preliminary draft of a final report have been completed; the final report is currently under technical review and should be available in 2015.

Brines and Underground Waste Disposal

Mapping Underground Brine-Disposal and Enhanced Recovery Wells

Disposal of oil-field brines and completion fluids by underground injection continues to be of interest in Kentucky as well as in neighboring states. Disposal wells inject brines that are brought to the surface with oil and gas production back into the same or similar porous underground formation from which they were initially produced. This practice of brine disposal also ensures the protection of underground sources of drinking water.

The U.S. Environmental Protection Agency maintains primacy by permitting and regulating all Class II wells in Kentucky under their Underground Injection Control program. Class II wells inject fluids associated with the oil and gas production.

Following the publication of "Class I Waste-Disposal Wells and Class II Brine-Injection Wells in Kentucky" (Map and Chart 204, series 12, 2013), **Tom Sparks** secured from EPA an additional Freedom of Information Act document listing all Class II wells in Kentucky, which contained an additional 2,927 enhanced oil recovery injection wells as recorded and maintained in EPA's well database. From this list, a spatial database was created. Using the same process as used in Map and Chart 204, more than half of EPA's Class II wells were successfully matched to the KGS oil and gas well database. Not all information was provided by EPA; some wells were missing well numbers, ground elevations, total depths, or latitude-longitude pairs, thereby limiting the final output. Since Kentucky has no regulatory authority over underground injection, including enhanced oil recovery wells, some of the wells may not have been so identified in the KGS database. The remaining wells without successful matches were plotted "as is" from the EPA location data.

Upon completion and final review of this new database, a new map service linked to the KGS petroleum map service and a possible new map will be made available in the next year. In addition, an update to Map and Chart 204 is planned as new brine-injection disposal wells continue to be permitted.

Development of a Brine Disposal Framework for the Northern Appalachian Basin

Marty Parris and **Tom Sparks** continued to participate in a project addressing issues associated with brine disposal in the Appalachian Basin. The project is led by Battelle Memorial Institute and participants include the state surveys of Kentucky, West Virginia, Pennsylvania, and Ohio. The goal is to develop a regional geologic framework for brine injection zones. The assessment will consider reservoir properties, such as injectivity and fracture strength, storage capacity, operations requirements, and potential costs under various combinations of brine source and injection sites. Using the assessment parameters, the project will model commercial-scale injection for select reservoirs in the study area. The deliverables are intended to provide guidance for oil and gas producers, regulatory agencies, and public stakeholders.

Research activities included supplying Battelle with three whole-core samples for rock mechanics (compressive, acoustic, and tensile strength testing) from the recently drilled KGS No. 1 Hansen Aggregates well in Carter County. Zones investigated were from the Rose Run Sandstone, porous Copper Ridge Dolomite section, and Mount Simon Sandstone.

At a project meeting, all partners, including KGS, presented each state's respective summary of current and potential injection zones. The preliminary injection test results from the No. 1 Hansen Aggregates well were presented at this meeting.

A list of all 30 active brine-injection wells in the study area along with associated operational data for the past 5 years (monthly volumes injected, average and maximum injection pressures) for 21 of these wells was provided to KGS by EPA. These data were then compiled and sent on to Battelle for input into their analysis and modeling. ❖

Water Resources

Staff explores water quality and availability

The Water Resources Section conducts research and collects data on Kentucky's groundwater and surface-water resources and provides public assistance to State, federal, and local agencies, university researchers, geoscientists and engineers in the private sector, and the general public. During fiscal year 2013-14, the section's activities were largely dominated by three issues: (1) sinkhole occurrences, (2) groundwater quality and availability, and (3) improvement in groundwater data availability.

Sinkholes and Karst-Related Activities

The sinkhole that occurred on February 12, 2014, at the National Corvette Museum in Bowling Green, Ky., captured the attention of national and international media, as well as the general public. The sinkhole resulted in a collapse of the museum's Sky-Dome exhibit area floor, causing significant damage to the building and eight vintage Corvette cars on display. Sinkholes are common

features in the karst area around Bowling Green, and are numerous in the vicinity of the museum's location. The formation of the sinkhole beneath the museum floor appeared to be triggered by the collapse of bedrock forming the roof of a large, relatively dry, and previously unknown remnant cave passage. The exact circumstances that triggered the bedrock collapse are unknown at this time, but are the subject of an ongoing investigation. Water Resources Section staff and **Dr. Jason Polk** and other geologists from Western Kentucky University have begun more direct collaboration to investigate sinkhole occurrences and other karst-related hazards in Kentucky and expect to conduct joint research in these areas in the future.

Left and below: The sinkhole collapse at the Corvette Museum in Bowling Green is inspected by KGS staff members from the Water Resources and Geologic Hazards Section with Dr. Jason Polk, professor of geology at Western Kentucky University on February 20.

In the weeks and months following the Corvette Museum sinkhole collapse, Water Resources staff members **Jim Currens** and **Chuck Taylor** responded to dramatically increased numbers of requests for interviews and information from print and television media, as well as calls and emails from concerned homeowners who reported sinkholes on their properties and sought help in assessing the severity of the problem and a remedy. Currens inspected more than 65 sinkholes on private property and provided information needed by homeowners to help remediate them. Currens and Taylor gave invited presentations on sinkholes and karst hazards at a series of engineering training seminars hosted in Somerset, Bowling Green, and Paducah by the Kentucky Society of Professional Engineers. Taylor also gave an invited presentation on sinkholes and karst at the Nature's Call to Action II Conference on April 9, 2014, co-hosted by the Kentucky Transportation Cabinet and the Kentucky Division of the Federal Highway Administration, and gave presentations on the Corvette Museum sinkhole collapse at the KGS annual meeting on May 16, 2014, and at the Association of American State Geologists annual meeting in Lexington on June 9, 2014.

Additional sinkhole- or karst-related research being conducted by Water Resources staff includes a project to improve sinkhole mapping using LiDAR technology, and a karst hydrology study in the Cane Run Basin. Since 1997, the section has collected information about the occurrence of cover-collapse sinkholes in Kentucky, maintaining an inventory of these features that describes their locations, physical characteristics, and topographic and geologic settings. A GIS file of sinkholes identified and mapped throughout the state at 1:24,000 scale was prepared in 2003 and is available for download at www.uky.edu/KGS/gis/sinkpick.htm. However, the recently improved availability of high-resolution LiDAR digital topographic data sets has provided a new avenue for improved mapping of surface features such as sinkholes, particularly in urbanized and suburbanized areas. In 2013-14, Water Resources hydrogeologist **Junfeng Zhu** has continued research using LiDAR data and new data-processing methods he developed during the previous year to improve sinkhole identification and mapping in Kentucky.

Zhu and UK Department of Earth and Environmental Sciences student **Bill Pierskalla** used the new data-processing methods to map sinkholes in surface watersheds in Bullitt, Jefferson, and Oldham Counties. Results obtained thus far demonstrate that the number of probable sinkholes identified from LiDAR mapping is approximately four times greater than the number identifiable using contoured depressions visible on topographic maps. A field inspection of sinkholes indicates that the LiDAR data-processing method developed by Zhu is 80 percent successful in identifying new sinkholes in the study area. This research is ongoing, and the objectives are to refine the method and extend the mapping area to other sinkhole areas of the Bluegrass Region of Kentucky. Zhu presented a talk on the new LiDAR sinkhole mapping project to the annual meeting of the Association of American State Geologists in Lexington on June 9, 2014.

In 2013-14, **Jim Currens** continued collaborative work with the UK College of Agriculture, Food and Environment on the Cane Run Basin karst hydrology project. Currens leads research directed at gathering field data needed to measure the discharge of groundwater and potential contaminants such as nitrate, phosphorus, fecal bacteria, and suspended sediments in the karst aquifer beneath the Cane Run surface drainage basin in Fayette and Scott Counties. He has collected and analyzed data using a variety of methods including quantitative dye-tracer tests, Doppler sonar, borehole flowmeter, and continuous water-quality monitoring at a field monitoring station at the Kentucky Horse Park. Continuous high-resolution data have been collected from wells drilled directly into the Royal Spring karst conduit—the major cave stream passage that underlies and drains part of the approximately 15,000 acres of the Cane Run Basin—in order to quantify and track changes in the discharge of subsurface water and contaminant concentrations through the conduit. The data and findings obtained by this project are aiding the UK College of Agriculture, Food and Environment and the Lexington-Fayette Urban County government in designing and implementing best management practices to improve stormwater disposal and water quality in the Cane Run Basin, a tributary of North Elkhorn Creek. This project continues into 2014-15.

Jim Currens introduces premeasured nontoxic fluorescent Rhodamine WT dye into a tub of water to begin a tracer test at the Kentucky Horse Park in the Cane Run Basin.

Groundwater Quality and Availability

Several ongoing and new projects in the Water Resources Section address issues related to groundwater quality and availability.

Junfeng Zhu, working with the Kentucky Research Consortium for Energy and the Environment, applied a groundwater flow and transport model to test the potential outcomes of different groundwater remedial actions in the aquifer system at the Paducah Gaseous Diffusion Plant, where a variety of radioactive and nonradioactive hazardous wastes were released in the past. The outcomes will be used to assist U.S. Department of Energy and other federal and State resource managers and contractors in remediating groundwater at the site. Zhu is also working with KGS staff in the Energy and Minerals Section to study the potential impacts of sulfur dioxide, when injected with carbon dioxide, on the Knox Formation in western Kentucky. Sulfur dioxide is one of the common residual gases in emissions from coal-fired power plants. Injecting sulfur dioxide with carbon dioxide is an attractive option because of the economic and environmental benefits of removing it from the atmosphere. Zhu is using a computer-modeling approach to simulate the potential effects of the injection, and the results suggest that adding sulfur dioxide can enhance chemical reactions among rock minerals, formation liquid, and injected gases, possibly causing changes in physical properties such as porosity and permeability of the Knox rocks. These findings are significant for determining whether the Knox Formation can be used for carbon sequestration.

Several new projects under development address the issue of groundwater availability. Water Resources staff participated in several public service projects to help various State and local officials assess groundwater availability for agricultural irrigation or municipal

water wells. **Glynn Beck,** working in collaboration with Kentucky Division of Water staff, inventoried high-yield irrigation wells in parts of the Jackson Purchase and Western Pennyroyal Regions, and helped make preliminary assessments about the suitability of the aquifers in these areas to provide the large quantities of withdrawal needed to economically operate large center-pivot irrigation systems. Recent increases in grains grown for biofuel production in Kentucky have resulted in increased interest in using groundwater for irrigation during potentially drier parts of the growing season. **Chuck Taylor** participated in an irrigation forum sponsored by the Kentucky Corn Growers and Small Grain Growers Associations in Princeton on August 1, 2013, and gave invited subsequent presentations at the joint Kentucky Small Grain Growers Association–Kentucky Small Grain Promotion Council business meeting on August 8 in Louisville and at the annual AgriBusiness Association of Kentucky 2013 annual meeting November 6 in Louisville.

Taylor and **Glynn Beck** also are members of the Kentucky Agricultural Science Monitoring Committee, an interagency group that evaluates and addresses science and environmental data needs related to agricultural interests. Beck also conducted a short-term public assistance project in response to a request from an agriculture-related industry interested in withdrawing groundwater from deep channel-sandstone aquifers known to be present in the southern part of the Western Kentucky Coal Field. Future projects currently under development by the Water Resources Section that will address various agricultural and other needs for improved groundwater data include a reestablished long-term statewide network of groundwater observation wells, aquifer testing, and mapping projects in the Jackson Purchase, Western Pennyroyal karst, and other areas. These projects are anticipated to begin in earnest in late 2014. **Glynn Beck, Steve Webb,** and **Bart Davidson** have made field visits in areas of interest to inspect water wells and collect borehole video or geophysical-log data on well construction in order to evaluate the suitability of wells for future aquifer testing or water-level monitoring (or both).

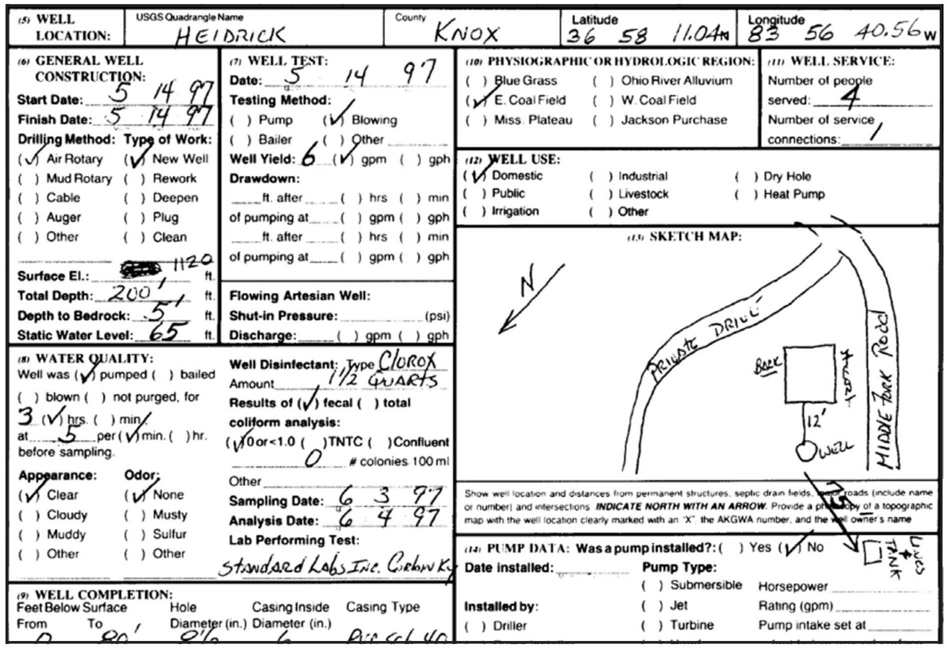
Glynn Beck prepares to insert a natural gamma probe into a well. The probe senses and records fluctuations in the natural gamma radiation emitted by various minerals and enables researchers to identify subsurface strata such as shale, sandstone, and limestone by their distinctive gamma-ray signatures.

Groundwater Data Repository

The Kentucky Groundwater Data Repository, initiated in 1990 by the Kentucky Geological Survey under mandate from the Kentucky legislature (KRS 151:035), was established to archive and disseminate groundwater data collected by State agencies, other organizations, and independent researchers. The data repository currently contains information on more than 97,000 water wells and 5,300 springs, as well as 50,000 suites of water-quality analyses (millions of individual analyte results). The repository contains data from more than 15 State, federal, academic, and private agencies, but the largest contributor continues to be the Kentucky Division of Water. The repository can be accessed at kgs.uky.edu/kgsweb/DataSearching/watersearch.asp.

In fiscal year 2013-14, the Division of Water supplied four uploads of water-well and water-quality data to the Survey, which were entered into the repository and made available to the public. In July 2013, nearly 300,000 scanned digital images of original drillers' logs and associated documents were provided by the Division of Water to the Survey, and were processed and placed online in October. One major benefit of scanned images is that all information visible on the original drillers' logs, including handwritten notes or drawings, can now be viewed and used as desired, including descriptions of geologic strata and depths of encountered water-bearing zones. Uploads of the scanned images take place biannually.

In a new initiative, data from the repository are being used to compile a digital Kentucky groundwater atlas web page. To date, more than 40 draft maps have been generated that show water-quality trends, groundwater levels, and water-well distribution and yield rates. Range-of-value maps for 32 water-quality parameters are currently available through the repository's groundwater-quality search engine, located at kgs.uky.edu/kgsweb/DataSearching/Water/WaterQualSearch.asp. Data available from aquifer tests that have been conducted across the state are also in the process of being compiled and will be made available in the near future via the digital atlas site.


(5) WELL LOCATION: USGS Quadrangle Name HEIDRICK County KNOX Latitude 36 58 11.04 N Longitude 83 56 40.56 W

(6) GENERAL WELL CONSTRUCTION: Start Date: 5 14 97 Finish Date: 5 14 97 Drilling Method: (✓) Air Rotary ( ) Mud Rotary ( ) Cable ( ) Auger ( ) Other Type of Work: (✓) New Well ( ) Rework ( ) Deepen ( ) Plug ( ) Clean Surface El.: 1120 ft. Total Depth: 200 ft. Depth to Bedrock: 5 ft. Static Water Level: 65 ft.

(7) WELL TEST: Date: 5 14 97 Testing Method: ( ) Pump (✓) Blowing ( ) Bailer ( ) Other Well Yield: 6 (✓) gpm ( ) gph Drawdown: ft. after ( ) hrs ( ) min of pumping at ( ) gpm ( ) gph ft. after ( ) hrs ( ) min of pumping at ( ) gpm ( ) gph Flowing Artesian Well: Shut-in Pressure: (psi) Discharge: ( ) gpm ( ) gph

(8) WATER QUALITY: Well was (✓) pumped ( ) bailed ( ) blown ( ) not purged, for 3 (✓) hrs. ( ) min. at 5 per (✓) min. ( ) hr. before sampling. Appearance: (✓) Clear ( ) Cloudy ( ) Muddy ( ) Other Odor: (✓) None ( ) Musty ( ) Sulfur ( ) Other Well Disinfectant: Type CLOROX Amount 1/2 QUARTS Results of (✓) fecal ( ) total coliform analysis: (✓) 0 or <1.0 ( ) TNTC ( ) Confluent 0 # colonies 100 ml Other Sampling Date: 6 3 97 Analysis Date: 6 4 97 Lab Performing Test: Standard Labs Inc. Corbin Ky

(9) WELL COMPLETION: Feet Below Surface From To Hole Diameter (in.) Casing Inside Diameter (in.) Casing Type

(10) PHYSIOGRAPHIC OR HYDROLOGIC REGION: ( ) Blue Grass (✓) E. Coal Field ( ) Miss. Plateau ( ) Ohio River Alluvium ( ) W. Coal Field ( ) Jackson Purchase

(11) WELL SERVICE: Number of people served: 4 Number of service connections: 1

(12) WELL USE: (✓) Domestic ( ) Public ( ) Irrigation ( ) Industrial ( ) Livestock ( ) Other ( ) Dry Hole ( ) Heat Pump

(13) SKETCH MAP:

Show well location and distances from permanent structures, septic drain fields, roads (include name or number) and intersections. INDICATE NORTH WITH AN ARROW. Provide a photocopy of a topographic map with the well location clearly marked with an "X," the AKGWA number, and the well owner's name

(14) PUMP DATA: Was a pump installed?: ( ) Yes (✓) No Date installed: Pump Type: ( ) Submersible ( ) Jet ( ) Turbine Installed by: ( ) Driller Horsepower Rating (gpm) Pump intake set at

An example from Knox County of one of the nearly 300,000 scanned digital images of original drillers' logs and other documents added to the Kentucky Groundwater Data Repository.

KGS Laboratory

In the fall of 2013, the KGS laboratory was restructured and administratively placed in the Water Resources Section to enhance collaboration and opportunities for synergistic research. As a consequence, the laboratory is better able to support the research and data needs of Water Resources hydrogeologists and their UK collaborators—for example, by providing analytical support for field samples collected for the previously mentioned Cane Run Basin project. As before, the KGS laboratory continues to assist other KGS researchers, University of Kentucky departments, and various State agencies by providing analysis for rock, oil, gas, and water samples collected throughout the state. For example, shale samples were analyzed for a KGS Energy and Minerals Section project investigating the total organic carbon content of the Utica Shale. Another project analyzed water from several deep wells, including brine water from the Knox Formation. Samples taken by UK Department of Civil Engineering researchers were analyzed to help determine the water quality of the South Elkhorn watershed. Water samples were analyzed for a Kentucky Transportation Cabinet project. The laboratory staff also analyzed surface-water samples collected under the Kentucky Watershed Watch program, which monitors the quality of the state's surface waters and wetlands.

The laboratory also houses, maintains, and oversees the scheduling of its X-ray diffraction instrument for students and research staff within the University of Kentucky research community for a wide variety of projects. Several students from the Department of Earth and Environmental Sciences worked with laboratory personnel on different research projects, looking at both water and shale samples. Samples from the UK Department of Mining Engineering were analyzed using X-ray fluorescence and a UK Department of Mining Engineering visiting scholar from China worked with KGS researchers and laboratory personnel to learn coal and coke testing techniques. ✤

Geologic Hazards

Hazards staff deals with earthquakes, landslides, and policy

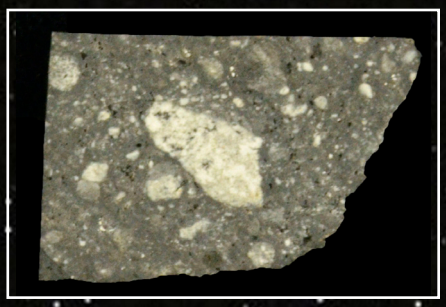
Seismologists in the Geologic Hazards Section continued to upgrade the Kentucky Seismic and Strong-Motion Network in 2013-14. With the addition of strong-motion accelerometers at three real-time stations (HEKY, LOKY, and SOKY in Henderson, Salem, and Sonora, respectively), near-real-time ground-motion measurements across most of Kentucky can now be made. Also, two more stations were converted from analog to digital data acquisition, increasing the sensitivity of the network to observe smaller earthquakes. A real-time data share with the neighboring seismic network operated by the University of Memphis continued. In addition, data from networks operating in and around Kentucky, including EarthScope USArray stations (www.earthscope.org/science/observatories//usarray) and the OIINK (Ozarks, Illinois, Indiana, and Kentucky) project (www.indiana.edu/~oiink), were acquired in tandem with real-time data from the Kentucky network and used to detect seismic events in Kentucky with unprecedented sensitivity.

Fourteen earthquakes occurred in the state during the fiscal year, with magnitudes from 0.2 to 2.7. Seven of these events happened in the Mississippi Embayment, and seven occurred in eastern Kentucky. Six of the earthquakes were felt by local residents. The largest of them, a magnitude-2.7 earthquake in Bracken County on July 23, 2013, caused cracks in the interior walls of some homes.

A video was posted on KGS's YouTube site, www.youtube.com/user/KGSUK. Users can scroll down to KGS Hazard Section Research to see the video "The Kentucky Seismic and Strong-Motion Network." It describes the current configuration of the network, graphical displays of network data available on the KGS website, and the different instruments installed to collect seismic data.

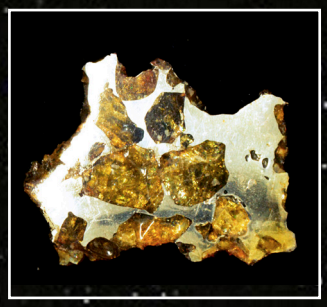
Using data from the network as well as EarthScope USArray and

Continued on page 18



Dhofar 280: Oman. Found: 2001. Type: Stony, achondrite lunar. Total known weight: 425 grams.

Ausson: Haute Garrone, France. Fell on Dec. 9, 1858. Type: Stony. Total known weight: aproximately 20.4 grams.



Admire: Lyon County, Kansas. Found 1881. Type: Stony-iron pallasite. Total known weight: approximately 180 kg.

Cumberland Falls, Ky. Fell: April 9, 1919.

Meteorite Collection Gets Major Boost

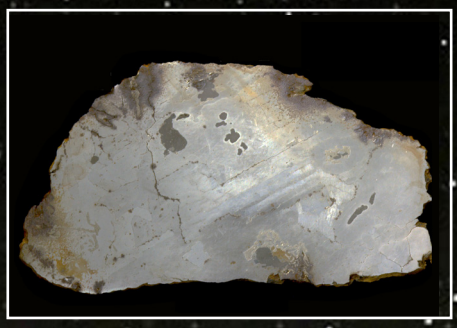
Retired civil engineer William Russell of Goshen, Ky., donated a large collection of meteorites to KGS in 2014. For 25 years, Russell collected meteorite specimens found in many locations around the world.

Among the Kentucky specimens is a sample of a meteorite that fell through the roof of a house near Burnwell, Pike County, September 4, 1990. The largest piece of this stony meteorite is a 3.3-pound portion that went on display in the Smithsonian Institution in 1997.

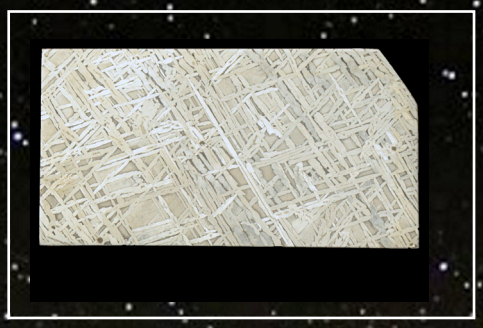
All of the meteorites in the Russell collection have been researched to determine their type, chemistry, and relationship to the early solar system. Warren Anderson of the KGS Energy and Minerals Section added some of the Russell collection to a cabinet displaying another collection of meteorites donated in 1999 by retired UK chemistry professor William Ehmann.

The donated specimens on these pages were cut from the original meteorites.

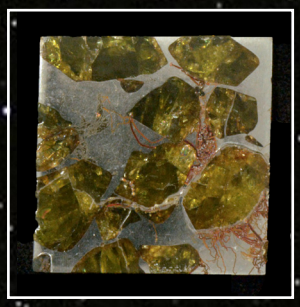
Lake Murray: Carter County, Oklahoma. Found: 1933. Type: Iron octahedrite. Total known weight: 267.6 kg.



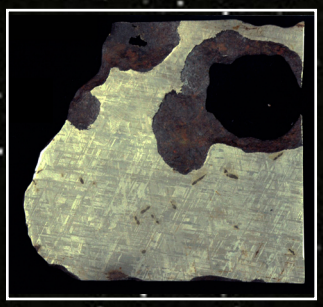
Carbo: Sonora, Mexico. Found: 1923. Type: Iron octahedrite. Total known weight: 495 kg.



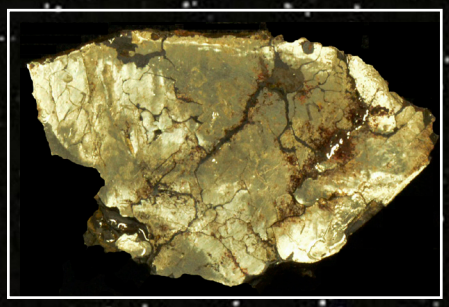
Boxhole: Plenty River, Northern Territory, Australia. Found: June 1937. Type: Iron octahedrite. Known total weight: 500 kg.



Fukang: China. Type: Stony-iron pallasite.



Gibeon: Great Namaland, Namibia, Africa. Found: 1836. Type: Iron octahedrite. Total known weight: 26,000 kg.



Clark County: Clark County, Ky. Found: 1937.

Uruacu: Goias, Brazil. Found: 1992. Type: Iron octahedrite. Total known Weight: 72.5 kg.

Mary Ann and William Russell

KGS student worker Bailee Hodelka and Warren Anderson sort and pack the donated collection.

Warren Anderson arranges the Russell collection in a display case at KGS.

Continued from page 15

University of Memphis stations, **Seth Carpenter, Ed Woolery,** and **Zhenming Wang** co-authored a paper, "The M_w 4.2 Perry County, Kentucky, Earthquake of 10 November 2012: Evidence of the Eastern Tennessee Seismic Zone in Southeastern Kentucky," published in *Seismological Research Letters.* A graduate student in the UK Department of Earth and Environmental Sciences began analyzing recordings from the Central United States Seismic Observatory to develop a master's thesis.

Landslide Hazards

The KGS landslide inventory database was augmented with new entries, bringing the total number of entries up to 2,256 by the end of the fiscal year. The information came from State government agencies, published maps, field investigations, LiDAR mapping, and reports from the public. An Information Circular documenting the creation of the landslide inventory database and its application is being prepared for publication. This database serves as a foundation for improving our understanding of landslides and provides information on mitigation to assist land-use planners, transportation officials, emergency managers, and the public. It has been used to create a landslide information map that has been added to the KGS Geologic Map Information Service (kgs.uky.edu/kgsweb/main.asp). The map shows the locations of known landslides and areas susceptible to landslides in a geologic and geomorphic context. It also provides an overall view of landslide hazards across the state.

Boreholes are drilled for instruments at a Boyd County site to monitor the landslide that damaged this home.

Matt Crawford downloads data gathered from instruments at a Boyd County landslide with help from Bethany Overfield of the Geologic Mapping Section.

The focus in 2013-14 was monitoring and characterizing a landslide in Boyd County, in the northeastern part of the Eastern Kentucky Coal Field. This study will determine the depth, shape, and velocity of the sliding mass, using various tools for a full site characterization. Hydrogeologic, precipitation, landslide material and strength properties, landslide movement, and surface and borehole electrical-resistivity data were collected. Analysis of the last year's data showed that landslide movement corresponded to periods of the most rainfall. Electrical-resistivity data showed contrasts that correlated to borehole stratigraphy, failure surface depth, and groundwater conditions. A manuscript describing this research and findings has been submitted for journal publication.

Cooperative Research

The Geologic Hazards Section continued cooperative work with academic units on the UK campus, particularly the Departments of Earth and Environmental Sciences and Civil Engineering, through joint projects, teaching, student advising, and hiring student assistants. **Zhenming Wang** served as a co-adviser for a master's student and a committee member for three master's students and one doctoral candidate. **Matt Crawford** conducted research with **Dr. Sebastian Bryson** of the UK College of Engineering on landslides and cavity detection using downhole resistivity. The section also helped researchers at Purdue University and Indiana University locate seismic stations in Kentucky for the OIINK project, acquire seismic data, and develop

a joint proposal submitted to the USGS National Earthquake Hazards Reduction Program.

Seismic Hazard and Mitigation Policy

Seismic hazard and mitigation policies remained a major emphasis for the Geologic Hazards Section in 2013-14. These efforts focused on better communication of seismic hazards through publications, presentations, and seminars and assessing policy impacts in Kentucky through informal interviews of government officials, local business persons, and other professionals. KGS submitted official comments on the 2014 national seismic hazard maps to the USGS and on a report, "Development of NIST Measurement Science R&D Roadmap: Earthquake Risk Reduction in Buildings," to the National Institute of Standards and Technology. Presentations on seismic hazards and design maps were made to the Kentucky Society of Professional Engineers seminar series in Paducah, Somerset, Bowling Green, Prestonsburg, and Lexington. A breakout session on seismic hazards and mitigation policy in the central United States was held at the 2014 Association of American State Geologists annual meeting in Lexington, June 8–13, 2014. KGS Special Publication 17 (series 12, 2014), "Earthquakes in Kentucky: Hazards, Mitigation, and Emergency Preparedness," was published to help the public better understand earthquakes, seismic hazards, and mitigation policy, as well as emergency preparedness for earthquakes.

Informal interviews of government officials, local business leaders, and other professionals were conducted by graduate student **Alice Orton** of the Department of Earth and Environmental Sciences. They were intended to determine the range of general knowledge about science and engineering practices in the New Madrid Seismic Zone and to identify local concerns in western Kentucky about the impacts of current scientific practice on public policy and the economy. These interviews indicated that overly stringent seismic-design requirements in the Jackson Purchase Region have a negative impact on economic development in the region.

China Scholarly Exchange and Cooperative Research

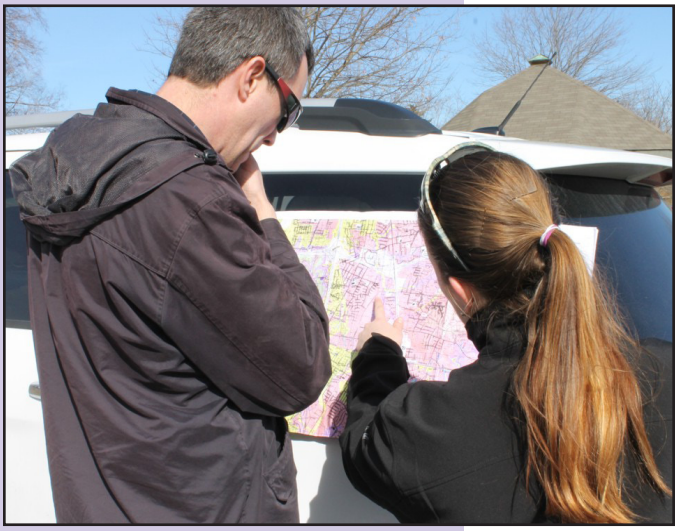
This was the 10th year for the exchange program between KGS and several institutes under the China Earthquake Administration. Three KGS staff—**Jim Cobb, Jerry Weisenfluh,** and **Zhenming Wang**—and a graduate student visited China and gave lectures at the Lanzhou Institute of Seismology, Earthquake Administration of Ningxia Province, and Institute of Engineering Mechanics in August 2013. Four visiting scholars from China came to UK to participate in research projects and exchanges. A report comparing ground-motion prediction equations between China's Wenchuan area and the central and eastern United States was submitted as a KGS publication. Data collected by graduate student **Alice Orton** during her visit to China was used as a part of her master's thesis. Wang co-authored a paper, "Seismic Hazard Assessment for Greater North China from Historical Intensity Observations," with visiting scholars **Jingwei Liu, Furen Xie,** and **Yuejun Lu;** it was published by the *Journal of Engineering Geology.* ❖

The KGS group visiting China poses at the "Earthquake Willow," split by the 1920 Haiyuan earthquake (M 8.5).

GEOLOGIC MAPPING

KGS mapping benefits Kentucky and its communities

Geologic maps of Kentucky provide valuable resources for citizens, government agencies, and geology-related industries. Mapping of the state's underlying geologic formations at a scale of 1:24,000 was completed by 1978, and contemporary mapping has focused on surficial deposits.



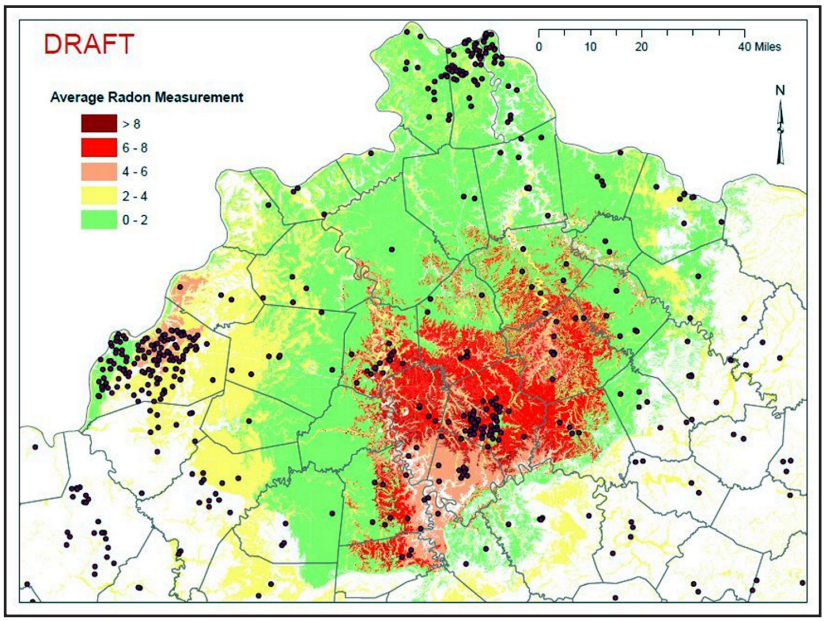
Section Head William Andrews and Antonia Hansen look at existing geologic maps of the Brooks quadrangle, where Hansen worked on surficial mapping.

During the fiscal year, Geologic Mapping Section staff continued working on 7.5-minute quadrangle surficial mapping projects, funded by the USGS STATEMAP program. **Antonia Hansen** completed a map of the Brooks quadrangle of southern Jefferson and northern Bullitt Counties and **Max Hammond** finished work on northern Kentucky's Union quadrangle. The Paducah East and West quadrangle maps were completed by **Scott Waninger,** with help from temporary employee **Amy Bleichroth**; both work out of the KGS office in Henderson. Section Head **William Andrews** finished the Anchorage quadrangle (Jefferson and Oldham Counties), and **Steve Martin** mapped the Georgetown quadrangle.

Martin also made progress on a sedimentological analysis of lakeshore transitions, where lake deposits meet uplands, in western Kentucky.

Bethany Overfield worked with staff in the KGS Geoscience Information Management Section on a new KGS mapping web service. She is gathering all the data developed since surficial mapping began in 2003 to make it publicly available through the existing KGS online mapping service. In the past, only drafts of the quadrangle maps have been available on the KGS website.

Overfield also collaborated with the Clean Indoor Air Project at the University of Kentucky College of Nursing to study the occurrence of radon in Kentucky and its effects on human health. She has overlain historical radon data sets compiled in the 1980's onto geologic maps to demonstrate a statistically significant variation in the radon levels measured in different parts of central Kentucky. This geologic approach will help the College of Nursing program to better target future radon measurements and



Preliminary geologic radon potential in north-central Kentucky, developed with KGS radon data sets compiled in the 1980's. This map is a product of Bethany Overfield's collaboration with the UK College of Nursing.

awareness efforts. Radon, which has no odor or taste and can enter buildings through foundations and plumbing, is the second leading cause of lung cancer in the United States.

Overfield has also been using KGS digital mapping data to create a number of different derivative products. She and **Matt Crawford** of the Geologic Hazards Section collaborated to develop a map showing geotechnical shale classifications and completed statewide and highway-district maps and reports on the geologic context of highway maintenance costs for the Kentucky Transportation Cabinet.

In a project funded by Jefferson County Emergency Management, **William Andrews** completed several engineering geologic maps of the Louisville area. The maps provide data on soil liquefaction potential and earthquake-induced landslides for disaster assessment software used by the local agency.

The Geologic Mapping Section continued to help university students develop geologic expertise. UK students **Julie Floyd** and **Michael Priddy** reviewed geotechnical reports and managed data for mapping projects; recent Morehead State University graduate **Justin Spears** helped to digitize the Salt Lick quadrangle surficial geologic map. ❖

Steve Martin operates soil sampling equipment near Waverly, Ky., as he examines lacustrine-upland transitions for the surficial mapping project.

Geologic Information Management

More geologic data available online

The main KGS website (www.uky.edu/KGS) served a diverse and international audience over the past fiscal year. It provided information about KGS, Kentucky resources, and geoscience education to 266,000 users from 216 countries. About 75 percent of the users were from the United States, and the remainder were from the United Kingdom, Canada, India, and Australia. About a third of U.S. users are in Kentucky, with the next most common users from California, Texas, Ohio, and Indiana.

Overall, there were about 1.2 million hits during the fiscal year. About 22 percent of the visits were by mobile and tablet users. Aside from the main page, the most popular pages on the KGS website were the fossil identification pages, followed by the rocks and minerals identification pages, seismic station recordings, educational resources pages, and the geology of Kentucky web pages.

The KGS database, maps, and publications search website (kgs.uky.edu/kgsweb) continues to serve a large and varied audience, receiving close to a million visits from 156 countries during the fiscal year. The great majority (91 percent) of visitors were from the United States, with the next most common from India, Canada, the United Kingdom, and Germany. In the United States, users from all 50 states and the District of Columbia visited the site; a little more than half were from Kentucky, and the next most common from Texas, Indiana, Pennsylvania, and Tennessee. Nearly 409,000 database searches were conducted by 130,000 users, which represents about a 5 percent increase in users over the previous year. There was a slight decrease (2 percent) in database searches from last year, primarily because of a decrease in searches for oil and gas data. There is continued growth with mobile and tablet users, with a 25 percent increase in usage over the 2012-13 fiscal year.

Liz Adams shoots video of Marty Parris at the Carter County deep research well for the KGS YouTube page.

KGS online map services were accessed close to 104,000 times, a slight increase over the previous fiscal year. There were more than 22,000 tabular data downloads, which was an increase of about 60 percent over the 2012-13 fiscal year. The total number of files downloaded exceeded 2.5 million, which is a slight increase over the last fiscal year. As in the past, users most frequently downloaded oil and gas records, online publications, coordinate conversion services, and data from the online geologic map server.

Updates to the web services included:

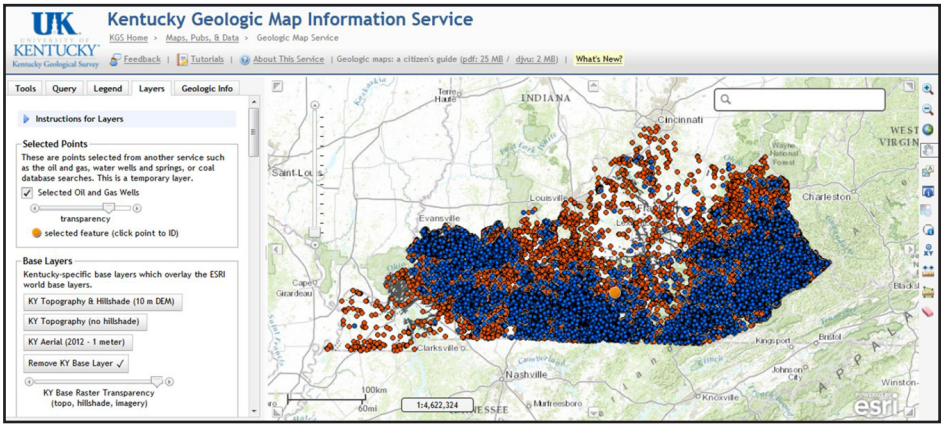
• Development and release of the Coal Resource Information map and data service, with funding support from the Kentucky Department for Energy Development and Independence.

• Restructuring the publications search pages to increase speed and functionality.

• Upgrading server hardware and software to provide a more stable web server and web GIS system.

Staff activities in the Geoscience Information Management Section included:

• **Elizabeth Adams** reviewed oil and gas well permit locations for the Kentucky Division of Oil and Gas (about 100 wells a month) and maintained the database of permits and well-location data. She developed a web map service, which is now available for visualizing oil and gas permit activity. She also continued supervising a student, **Bailee Hodelka,** from the UK Department of Earth and Environmental Sciences, who is



compiling and scanning oil and gas well documents for archiving and web dissemination. Hodelka also developed an instructional manual to help future students who scan these documents.

• Section staff maintained the Kentucky hub for the grant-supported Association of American State Geologists National Geothermal Data System. The system provides GIS services for 13 state geological surveys in the Southeast.

• Staff also prepared KGS geothermal data and submitted it to the National Geothermal Data System. Most Kentucky data consist of various types of well-location information, oil and gas top-of-formation data, borehole temperatures, and geologic map data. The data are available through public web-accessible services in the AASG National Geothermal Data System, which is populated with geothermal-relevant data from all 50 states.

• **Richard Smath,** with the help of geology student **Patrick Whalen,** prepared and scanned more than 60 years of legacy geologic field notes from KGS limestone exploration programs for the 2012-13 USGS National Data Preservation Project. This project cataloged and scanned notes collected since 1949 from 234 field sites, including measured sections, diagrams, photographs, unit descriptions, and rock samples and their analyses. These data will be made web-accessible at some point in the future.

• The 2013-14 USGS National Data Preservation project scanned legacy oil and gas well documents from the KGS Henderson office. A University of Southern Indiana student, **Kristen Schmeisser,** is the primary scanner. Through June 2014, documents from about 11,500 oil and gas records were scanned, resulting in the addition of 1,046 records to the KGS oil and gas database.

• With support from the Kentucky Watershed Watch, **Rebecca Wang** developed a website for Watershed Watch data managers to enter both field and laboratory data. Wang is also developing a website for both data collectors and the general public to visualize the data.

• Section personnel maintained and updated a KGS YouTube channel, which includes both instructional videos about KGS website usage and presentations about the work of the KGS. About 20 videos have been created for the KGS YouTube channel. ❖

Well Sample and Core Library

The large collection benefits research and exploration

The resurgence in Devonian and Cambrian shale gas nationally, in part because of new advances in exploration, software modeling techniques, and new drilling and stimulation technologies, has brought an upsurge in exploration and increased production. This trend was reflected in this year's utilization of the Well Sample and Core Library's collection.

The Core Library hosts professional development opportunities, including this review course for geologists interested in taking professional exams, led by Geologic Mapping Section Head William Andrews.

Devonian and Cambrian mudstones dominated research activities at the facility. This research was conducted by 82 exploration scientists representing 15 companies, including ExxonMobil, Chesapeake Energy, Cabot Oil and Gas, Cimarex Energy, Southwestern Energy, and SM Energy. Researchers looking ever deeper into previously investigated horizons in the Appalachian and Illinois Basins, or reassessing the production of younger, shallower deposits, examined more than 293,000 feet of well cuttings and cores.

The new discoveries of hydrocarbons in the Utica Shale of New York and West Virginia have reenergized interest in this horizon, and that interest in this play has translated south toward the commonwealth. A new oil play in the Berea sand that was discovered in Breckinridge County has also piqued the interest of industry. Because of previous production from these plays in Kentucky, the Well Sample and Core Library had

Patrick Gooding and Ryan Pinkston take geology students and professors from Michigan on one of the many tours of the facility.

cores and well cuttings that were readily available for examination and scientific testing. That helped the KGS Energy and Minerals Section form consortiums for studies to further our understanding of the petroleum systems of these two formations.

Researchers requested more than 1,400 samples for geochemical and physical properties testing. The materials available at the core library allowed KGS scientists, industry researchers, professors, and graduate and undergraduate students to facilitate their investigations by taking advantage of the extensive collection.

In addition, geology professors and their students on their way to and from field camp, Whitney Young Scholars from Louisville, and ExxonMobil researchers visited the facility.

The Core Library provided a work study position for a gifted student from Fayette County's Experienced-Based Career Education Program, Katlyn Sewell, shown with the facility's staff.

Henderson Office

A western Kentucky presence for more than 60 years

KGS has maintained a presence in western Kentucky since about 1950, when **R.E. Puryear** first opened an office in the Henderson city government building. The office has also been located in the National Guard Armory and Henderson Community College. The current location is owned by the University of Kentucky.

Glynn Beck and Steve Webb set up a downhole camera to inspect a well at White Plains in Hopkins County.

The facility is staffed with an office manager and members of the KGS Water Resources and Geologic Mapping Sections. Office Manager **Dave Williams** first came to the Henderson location during the Western Kentucky Coal Resource Study of the mid-1970's. Soil sampling equipment and a sediment laboratory are located there for research in the western part of the state. The office also responds to assistance requests from local governments and industrial and agricultural interests, while also doing educational outreach.

Staff at the office have assisted with significant recent KGS research in areas such as carbon storage, enhanced oil and gas recovery, water-quality sampling, and geologic mapping.

During the fiscal year, Henderson staff presented outdoor classroom enrichment courses on geology and water quality at the Jeffers Bend Environmental Center and Botanical Garden in Hopkinsville and the Pennyrile Resource Conservation and Development Offices.

Williams, along with **Scott Waninger** and **Amy King,** investigated a large landslide at the closed Ledbetter Bridge near Paducah. Williams also described cores taken from tar-sand deposits in western Kentucky. ❖

Amy King measures a scarp at the landslide near the closed Ledbetter Bridge.

Publications

Research results are available through KGS publications

Eleven new publications were produced by KGS staff during the fiscal year. Among the highlights: Three publications on research from the Hancock County deep carbon storage well drilled in 2009:

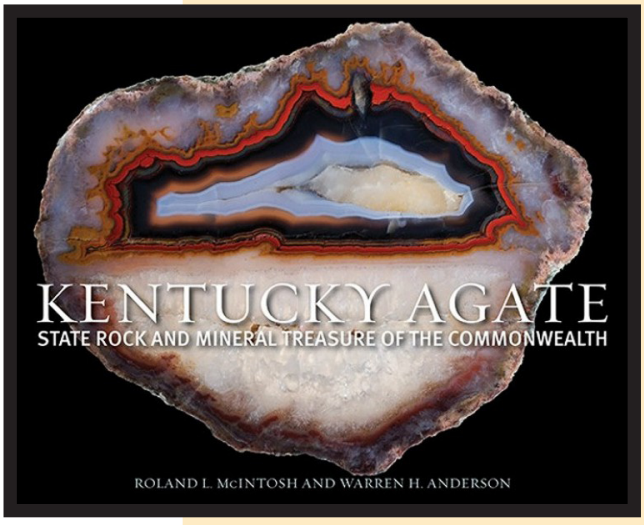
- "Geology of the Kentucky Geological Survey Marvin Blan No. 1 Well, East-Central Hancock County, Kentucky," by **Rick Bowersox** and **Dave Williams** (Report of Investigations 25, series 12, 2014)
- "Middle and Late Devonian New Albany Shale in the Kentucky Geological Survey Marvin Blan No. 1 Well, Hancock County, Kentucky," by **Brandon Nuttall** (Report of Investigations 17, series 12, 2013)
- "Evaluation of Phase 2 CO_2 Injection Testing in the Deep Saline Gunter Sandstone Reservoir (Cambrian-Ordovician Knox Group), Marvin Blan No. 1 Well, Hancock County, Kentucky," by **Rick Bowersox** (Contract Report 53, series 12, 2013)

"Hydrogeologic Investigations of Pavement Subsidence in the Cumberland Gap Tunnel" was written by **Jim Dinger, Jim Currens, Junfeng Zhu, Steve Webb, Brad Rister, R.C. Graves, David Allen,** and **Tim Scully** (Report of Investigations 27, series 12, 2014)

"Review of Kentucky Oil and Gas Production, 2010" was produced by **Brandon Nuttall** (Information Circular 30, series 12, 2014)

Kentucky Agate: State Rock and Mineral Treasure of the Commonwealth

This book was written by KGS research geologist **Warren Anderson** and agate collector **Roland McIntosh** and published by the University Press of Kentucky. It was the result of interested people contacting Anderson about the formation and geology of Kentucky's official state rock. It includes information on history and types of agate, its geologic setting, and how it forms. Multiple full-color photographs illustrate the 224-page book, along with detailed maps of the region in east-central Kentucky where colorful agate specimens can be found. ❖

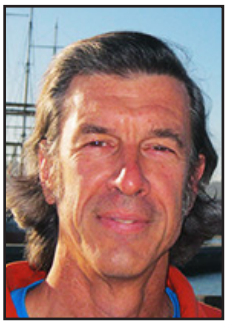


Public Outreach

Annual events provide geologic development and science education

The KGS annual seminar has become the largest gathering of geologists in Kentucky each year. This year's theme, "Monitoring Kentucky: LiDAR and Other Technologies," drew about 145 practicing geologists, professors, and students to the KGS Well Sample and Core Library. Ten speakers addressed aspects of the seminar theme, and the Kentucky Section of the American Institute of Professional Geologists and the Geological Society of Kentucky also presented their annual awards at the event.

KGS sponsors earth science lectures each year. American Association of Petroleum Geologists Distinguished Lecturer **Joe Stefani** of Chevron Energy Technology Corp. gave a talk called "The Earth Is Cleverer Than You Are: Learnings in Earth and Seismic Modeling" on February 25, 2014.

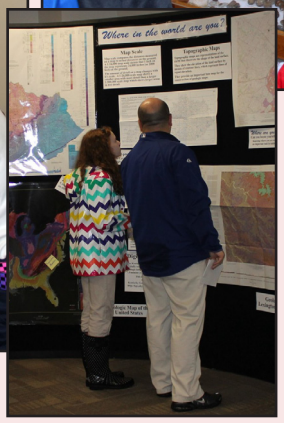


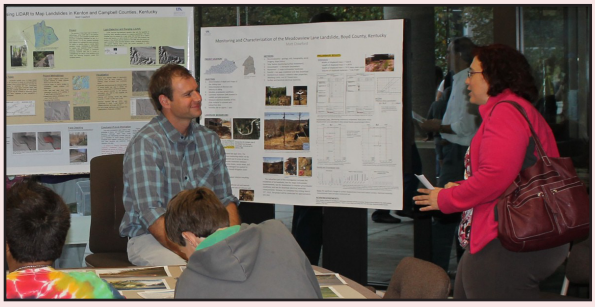
Andrew H. Knoll of the Harvard University Departments of Organismic and Evolutionary Biology and Earth and Planetary Sciences presented the annual Darwin Lecture in April 2014. "The Deep History of Life: What Kinds of Life Characterized Earth During the Precambrian?" was his topic.

The KGS Well Sample and Core Library frequently provides a location for conferences and meetings. The facility hosted 18 meetings, short courses, and workshops attracting 645 participants during the fiscal year.

Science Education Open House

Everyone Welcome





KGS holds an open house each year in conjunction with Earth Science Week. More than 170 students, parents, and teachers came to the event in October 2013 to browse and learn from 20 displays and demonstrations on earth science topics. One of the new demonstrations this year was set up by **Pete Idstein** of the UK Department of Earth and Environmental Sciences. He drew a crowd each time he set off his volcano demonstration outside the building, using a plastic bottle of liquid nitrogen dropped into a barrel of water. Other displays were set up by KGS staff, research offices at UK, earth science societies in Kentucky, and the Blue Grass Gem and Mineral Club. ❖

Research Projects Fiscal Year 2013-14

COMMUNICATIONS OUTREACH

Communications Specialist Liaison for the Kentucky Board of Registration for Professional Geologists
FY funding: $7,700
End date: 6/30/2014
Funding source: Kentucky Board of Registration for Professional Geologists

ENERGY

Carbon Management

An Evaluation of the Carbon Sequestration Potential of Cambro-Ordovician Knox Strata
End date: 4/30/2014
Funding source: U.S. Department of Energy through Illinois State Geological Survey

CO_2 Sequestration and Enhanced Oil and Gas Recovery Using CO_2
End date: 6/30/2015
Funding source: Governor's Office of Energy Policy

Midwest Regional Carbon Sequestration Partnership in the Appalachian Basin
FY funding: $100,031
End date: 12/6/2017
Funding source: U.S. Department of Energy through Battelle Memorial Institute

Oil and Gas Resources

Chronostratigraphic Age Dating of the Betsie Shale
FY funding: $5,002
End date: 1/31/2014
Funding source: U.S. Geological Survey

Utica Shale Appalachian Basin Exploration Consortium
FY funding: $155,301
End date: 6/30/2014
Funding source: West Virginia University

GEOLOGIC INFORMATION

Coal Information

Computerized Coal Resources for the National Coal Resources Data System
FY funding: $15,000
End date: 6/30/2015
Funding source: U.S. Geological Survey

Data Dissemination

National Geologic and Geophysical Data Preservation Program
FY funding: $28,398
End date: 8/31/2014
Funding source: U.S. Geological Survey

National Geothermal Data System Program
End date: 12/31/2014
Funding source: U.S. Department of Energy through Arizona Geological Survey

GEOLOGY

Geologic Communication

Online Roster for Kentucky Board of Registration for Professional Geologists
FY funding: $4,981
End date: 6/30/2014
Funding source: Kentucky Board of Registration for Professional Geologists

Geologic Mapping

Engineering Geologic Maps for Jefferson County Emergency Planning
End date: 6/30/2014
Funding source: Federal Emergency Management Agency through University of Louisville

Quaternary and Surficial Geological Mapping for Multiple Applications in Kentucky
FY funding: $187,320
End date: 7/31/2014
Funding source: U.S. Geological Survey

Subsurface Investigations

Development of Subsurface Brine Disposal Framework in the Northern Appalachian Basin
FY funding: $25,138
End date: 3/31/2015
Funding source: U.S. Department of Energy through Battelle Memorial Institute

HAZARDS

Seismic Monitoring

Installation of the Central U.S. Seismic Observatory
End date: 9/30/2013
Funding source: U.S. Department of Energy through Center for Applied Energy Research

WATER RESOURCES

Groundwater Monitoring

Groundwater Modeling at the Paducah Gaseous Diffusion Plant
End date: 9/30/2013
Funding source: U.S. Department of Energy through Center for Applied Energy Research

Water Information

Feasibility Study for Compiling a National Groundwater Quality Database
FY funding: $16,750
End date: 9/29/2013
Funding source: Center for Disease Control through Kentucky Division of Water

Watershed Watch of Kentucky Web-Based System for Data Preservation
FY funding: $50,000
End date: 12/31/2014
Funding source: Watershed Watch of Kentucky Inc.

Staff Awards and Recognitions

Bethany Overfield continued to serve on the Board of Directors for the Kentucky River Watershed Watch and was appointed treasurer of the organization.

Rick Bowersox received recognition from the California Board for Professional Engineers, Land Surveyors, and Geologists for 35 years as a professional geologist, a milestone he reached on January 19.

Jerry Weisenfluh was appointed to the USGS National Cooperative Geologic Mapping Program Database steering committee. He also holds the state geologist position on the Kentucky Board of Registration for Professional Geologists.

Bart Davidson serves as a member of the Kentucky Water Well Drillers Certification Board, which reviews qualifications and requirements for drillers to be certified by the State. It also provides oversight on water-well drilling issues and regulations of the Kentucky Division of Water.

Jim Currens was recognized with the Bill Barfield Award for Outstanding Water Resource Research by the Kentucky Water Resources Research Institute. The award cited

Currens's extensive data collection, mapping, and analysis of karst systems in Kentucky.

Currens also received the Outstanding Kentucky Geologist Award from the Kentucky Section of the American Institute of Professional Geologists during the 2014 KGS annual seminar.

Retired State Geologist **Jim Cobb**

was presented with the Distinguished Service Award from the Geological Society of Kentucky and a Lifetime Achievement Award from KY-AIPG. The U.S. Geological Survey also recognized his outstanding contribution to science and his career of service to Kentucky.

William Andrews served on the Kentucky Geographic Information Advisory Council.

Matt Crawford served as secretary of the Geological Society of America Environmental and Engineering Geology Division and as a member of the organizational committee for the Geohazards in Transportation in the Appalachian Region Forum.

Patrick Gooding was reelected secretary/treasurer of the Geological Society of Kentucky and a GSK delegate to the American Association of Petroleum Geologists House of Delegates. He has served on four AAPG committees, including the Preservation of Geoscience Data, Public Outreach, Field Safety, and House of Delegates Honors and Awards committees.

Ray Daniel was elected councilor at large for the Geological Society of Kentucky.

Geologic Information Management Section Head

Doug Curl serves on the Board of Directors for the Kentucky River Watershed Watch and also represents KGS on the State Geographic Information Advisory Council.

Chuck Taylor and **Glynn Beck** serve as members of the Kentucky Agricultural Science Monitoring Committee, an interagency group that evaluates and addresses science and environmental data needs related to agricultural interests, and Taylor is an appointed member of the Kentucky Agricultural Water Quality Authority.

KGS Staff

Fiscal Year 2013-14

STATE GEOLOGIST'S OFFICE

Cobb, Jim
State Geologist/Director

Weisenfluh, Jerry
Associate Director

Haney, Don
State Geologist Emeritus

ADMINISTRATIVE

Ellis, Kati
Administrative Staff Officer II

Long, Mandy
Administrative Support Associate I

Phillips, Gwen
Staff Support Associate II

ENERGY AND MINERALS

Harris, Dave
Section Head

Anderson, Warren
Geologist V

Bowersox, Rick
Geologist IV

Eble, Cortland
Geologist V

Greb, Steve
Geologist V

Grider, Jerrad
Student Worker

Hickman, John
Geologist IV

Nuttall, Brandon
Geologist V

Parris, Marty
Geologist V

Sparks, Tom
Geologist III

GEOLOGIC HAZARDS

Wang, Zhenming
Section Head

Brengman, Clayton
Student Worker

Carpenter, Seth
Geologist IV

Crawford, Matt
Geologist III

Song, Jindong
Temporary Technician

Woolery, Ed
Geophysics Faculty Associate

Xie, Zhuojuan
Temporary Technician

Liu, Kun
Temporary Technician

Potter, Grondall
Student Worker

GEOSCIENCE INFORMATION MANAGEMENT

Curl, Doug
Section Head

Adams, Elizabeth
Geologist I

Ellis, Mike
Computer Support Specialist II

Hodelka, Bailee
Student Worker

Hosseini, Ashkan
Student Worker

Pulliam, Carrie
Geologist II

Smath, Richard
Geologist III

Thompson, Mark
Information Technology Manager I

Ulanday, Joe
Temporary Technician

Wang, Rebecca
Database Analyst

Whalen, Patrick
Student Worker

Rohrer, Sean
Student Worker

COMMUNICATIONS AND OUTREACH

Weisenfluh, Jerry
Section Head/Associate Director

Banks, Roger
Stores Supervisor

Bratcher, Jordan
Student Worker

Essex, Caleb
Student Worker

Hounshell, Terry
Chief Cartographic Illustrator

Lynch, Mike
Technology Transfer Officer

Hower, Judy
Temporary Technician

Rulo, Collie
Senior Graphic Design Technician

Smath, Meg
Geologic Editor

GEOLOGIC MAPPING

Andrews, William
Section Head

Floyd, Julie
Student Worker

Hammond, Max
Geologist I

Hansen, Antonia
Geologist I

Martin, Steve
Geologist III

Overfield, Bethany
Geologist III

Priddy, Michael
Student Worker

Spears, Justin
Student Worker

LABORATORY

Backus, Jason
Scientist II/Laboratory Manager

Conner, Andrea
Scientist I

Mock, Steve
Scientist I

WATER RESOURCES

Taylor, Chuck
Section Head

Davidson, Bart
Geologist IV

Currens, Jim
Geologist V

Webb, Steve
Geologist II

Zhu, Junfeng
Geologist V

Pierskalla, Bill
Student Worker

Caudill, Robin
Student Worker

Shelton, Brittany
Student Worker

Taylor, Patrick
Student Worker

WELL SAMPLE AND CORE LIBRARY

Gooding, Patrick
Geologist IV/Manager

Daniel, Ray
Principal Research Analyst

Pinkston, Ryan
Research Analyst

Young, Denzel
Student Worker

WESTERN KENTUCKY OFFICE AT HENDERSON

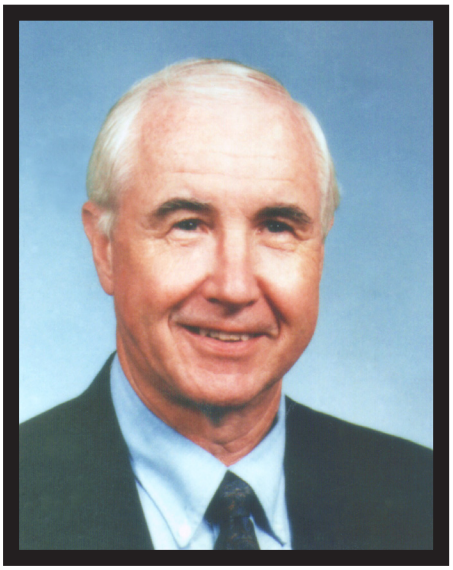
Williams, Dave
Section Head

Beck, Glynn
Geologist IV
(Water Resources Section)

Bleichroth, Amy
Temporary Technician

Waninger, Scott
Geologist II
(Geologic Mapping Section)

Schmeisser, Kristen
Student Worker



Former State Geologist Don Haney Dies at 79

Retired KGS Director and State Geologist Donald Haney died on June 8, 2014, at the University of Kentucky Hospital.

A Pulaski County, Ky., native, Haney is survived by his wife Shirley, a daughter, and a granddaughter.

He served as state geologist from 1978 to 1999, overseeing major growth in the Survey and participating in state and national legislative efforts. Haney was one of the principal authors of the 1992 National Geologic Mapping Act, and he proposed legislation passed by Kentucky's General Assembly to create the state's Groundwater Monitoring Network and the Groundwater Data Repository. He was instrumental in the passage of a law establishing the Kentucky Board of Registration for Professional Geologists and served as a board member for 7 years. He worked with UK, industry, and public officials to develop plans and help coordinate construction of the Mining and Mineral Resources Building at UK, where KGS is located, as well as a new Well Sample and Core Library.